COMPACT PICOSECOND PULSE RADIOLYSIS SYSTEM USING PHOTO–CATHODE RF GUN*

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Abstract

High-tech research centre project, which was started in 1999, has been approved its second phase of research in 2004 from the government. In this project, we have installed high quality electron beam system based on the RF photo-cathode at Kikui-cho campus of Waseda University. In second phase of the project, improvement of beam quality and developments of applications using the system have been improved. Beam quality has been improved by modified injection of laser beam onto the photo-cathode and obtained about 3mmmrad with the beam charge of 100 pC. Using the system, we have performed picosecond pulse radiolysis experiments for the measurements of rise signal for hydrated electron at 720nm, which is the peak band of the species. Thus, we have obtained the time resolution of the experimental system to 16ps in FWHM.

INTRODUCTION

High quality beam generation project has been started in 1999 under the fund of high-tech research centre project of the Ministry of Education, Culture Sports, Science and Technology. The first phase of the project was successfully concluded in March 2004. The second phase of project has been approved for further development of high quality beam generation and the applications as the five year project. In the second phase, we have been challenging the generation of very low emittance electron beams. At the same time, we have been developing the beam diagnostic system and beam applications, such as soft X-ray generation for microscope and pico-second pulse radiolysis by using the relatively low energy electron beam around 5MeV. The picosecond pulse radiolysis is one of the very powerful methods to study very early events in radiation chemistry. Generally, the pulse radiolysis experiments are performed by using large accelerator system, on the other hand, we have designed very compact system using photo-cathode RF gun.

RF GUN SYSTEM

RF Gun

RF gun system is composed of the BNL type 1.6 cells s-band rf cavity with Cu cathode[1,2], a set of solenoid magnets for emittance compensation[3], a stabilized Nd:YLF laser and rf power source. The rf cavity has been very precisely manufactured at KEK by single crystal diamond turning with the Cu processed by HIP (Hot Isostatic Pressing). The electron beam is emitted from the photo-cathode by irradiation of UV light (262nm, which is 4th harmonics of Nd:YLF fundamental light). Thus, the characteristics of electron beam are controlled by laser injection timing, timing structure and profile of laser beam on the photo-cathode. The photograph of the RF gun system is shown in Figure 1

Figure 1: RF gun system at Waseda Univ.

Laser System

All solid state picosecond Nd:YLF laser system named PULRISE-V, which has been developed by Sumitomo Heavy Industries (SHI) is applied for the irradiation of photo-cathode of Cu. The laser system has an active timing stabilization with the SESAM and PZT, and intensity stabilization system using $\lambda/4$ plate. As the results of the measurement, the timing fluctuation between the seed laser and reference signal from rf was less than 0.3ps. Thus we can apply the laser system for the source for electron generation and probe light for the pulse radiolysis experiments with the time resolution in picosecond region.

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EMITTANCE OF ELECTRON BEAM

Emittance of Electron Beam

The double slit scan technique is selected for the emeittance measurement for relatively low energy electron beam. As well-known, low energy electron beam should be affected by space charge in the measurements using Q scan technique. On the other hand, slit scan technique require somewhat tong time to measure the emittance but can obtain relatively precise emittance data. Thus, we have demonstrated double slit scan technique for characterize the electron beam using three different laser injection methods as shown in Figure 2. In the grazing injection, we can apply very simple optical system with higher electron charge compared to solid angel injection, which is realized by polarization of laser light. However, for obtaining lower emittance, profile modification on the photo-cathode has been required. That is, the simple grazing injection, the laser beam profile is coming to oval and this should lead worse emittance. Hence, we modified the laser beam profile using two-prism system to obtain the circular profile on the cathode.

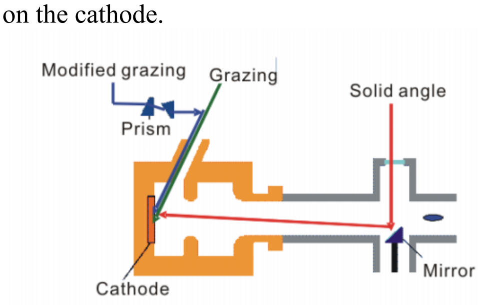

Figure 2: Laser injection techniques.

Figure 3 shows emittance data obtained for three different injections as the function of laser injection phase. The injection phase at 10 degree is corresponding to electron charge of 100pC and 30 degree is corresponding to 300pC

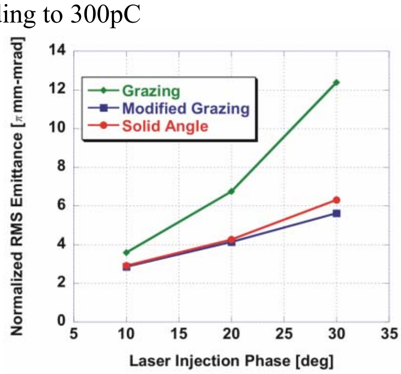

Figure 3: Measured emittance.

PULSE RADIOLYSIS EXPERIMENT

Pulse Radiolysis Technique

The pulse radiolysis technique is one of the most powerful methods to perform time resolved experiments to know the primary processes and dynamics of physical and chemical reactions in picosecond time region. In the pulse radiolysis experiment, the very short electron pulse for pumping the reaction and very short light for the probing the reaction are required in the technique in stroboscopic pulse radiolysis. The importance of the system is controlling the timing between pump beam and probe light. As described above, the timing jitter between seed laser and rf is less than 0.3ps. The probe light, which is white light, for our system is generated by the non-linear effect of IR laser from PULRISE V laser system by the injection to water cell. This means that the origin of pump beam and probe light is same laser. Thus, we can operate the pulse radiolysis experiments with very precise timing synchronization[4]. The development of stable probe light generation was one of the key technologies for the system. The test results for the stabilization are described in following section.

Probe Light Stabilization

As described above, the probe light is generated through the non-linear effect of laser light introducing to water cell. We have examined the improvement of IR laser light path, configuration of water cell and light path to detectors. Especially we have tested the configuration of water cell and white light focusing system to optical detectors.

We have demonstrated the stabilization through these improvements, and the results before and after the improvement are shown in Figure 4-a and -b, respectively.

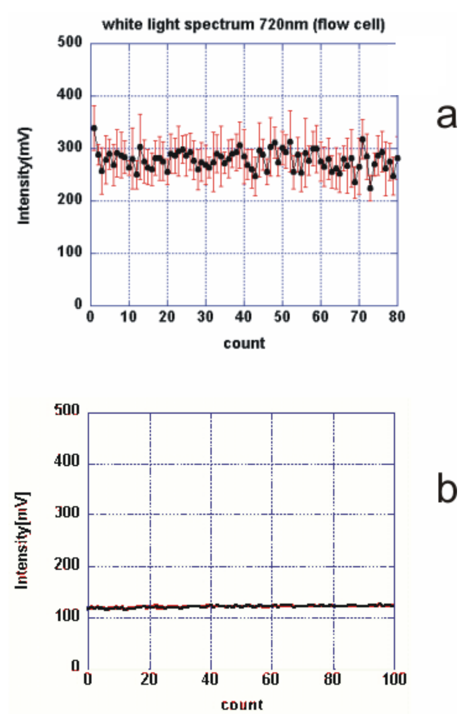

Figure 4-a and –b: White light stability before and after the improvements.

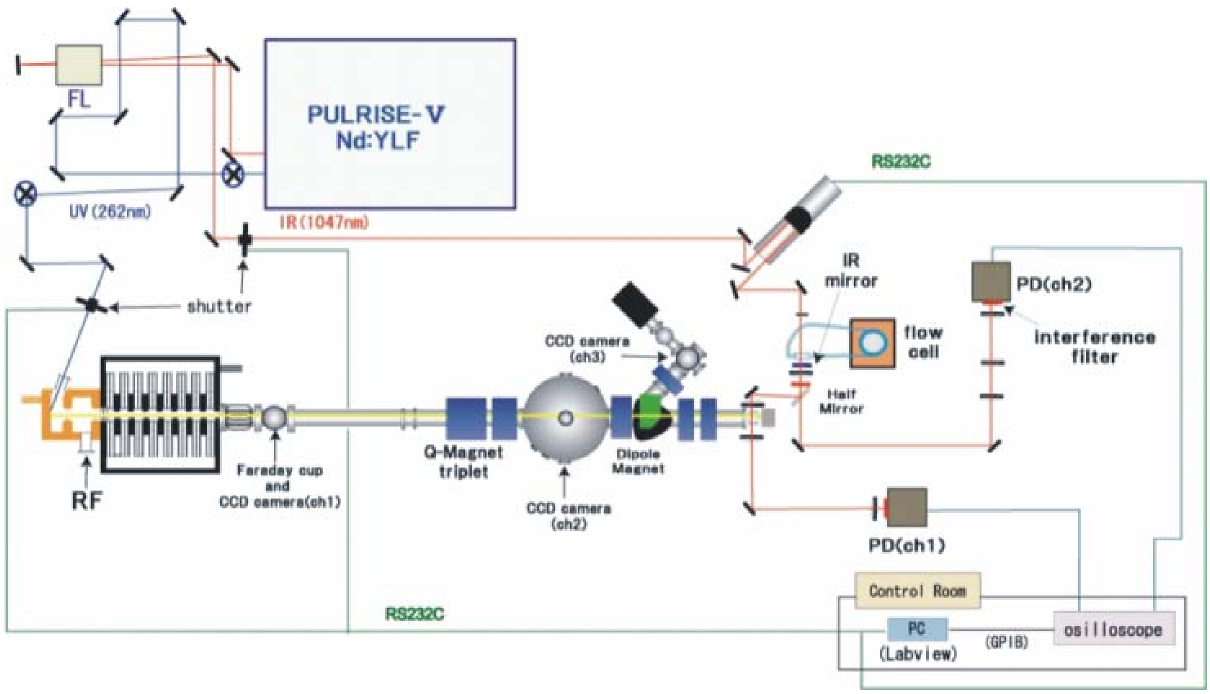

Figure 5: The system configuration at Waseda University.

System Configuration

The system configuration of our system is shown in Figure 5. To improve the time resolution of the system, we have prepared the beam focus system close to beam output window. Thus, beam size at the sample cell was minimized and the simulation result of time resolution gives us around 20ps in FWHM. The time resolution was estimated by following equation

Time Resolution(estimatedvalue)

$$\sigma = \sqrt{\sigma_{bd}^{2} + \sigma_{Ls}^{2} + n^{2}(\sigma_{bs}^{2} + \sigma_{Ld}^{2})}[ps]$$

$$\begin{Bmatrix} \sigma_{bd} : \text{bunch length}, \sigma_{Ls} : \text{laser size} \\ \sigma_{bs} : \text{beam size}, \sigma_{Ld} : \text{laser pulse length}, \\ n : \text{refractive index}(1.3) \end{Bmatrix}$$

Here, the values of σ_{bd}, σ_{Ls}, σ_{bs} and σ_{Ld} are 6, 0.1, 3.5 and 4.8 in FWHM, respectively.

After the optimization of the system, we have demonstrated the time resolution experiment by the measurement for the formation time of hydrated electron, which is known as very fast formation time within 1ps. The result of stroboscopic pulse radiolysis experiment monitored at 720 nm is shown in Figure 6. RMS rise time can be calculated as 6.9 ps, therefore, the rise time of the system is to be 16ps in FWHM

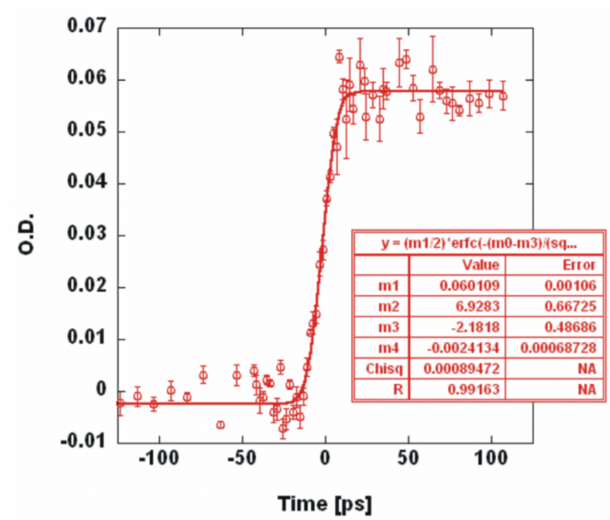

Figure 6: Rise of hydrated electron demonstrated by the improved system.

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